Agreement of treatment recommendations based on digital vs plaster dental models

Hsiu-Ching Ko,[a] Weitao Liu,[a] Derek Hou,[a] Sepideh Torkan,[a] Charles Spiekerman,[b] and Greg J. Huang[a]
Seattle, Wash

Introduction: The purpose of this study was to investigate differences in orthodontists' treatment plans based on digital models compared with plaster models. Additionally, we assessed whether digital or plaster models influence the reliability of orthodontists' treatment plans, as well as the amount of time required to arrive at the plan. **Methods:** Sixteen orthodontists planned treatment for 20 patients at 2 time points using either the same or different model formats (digital or plaster). The treatment plan decisions and time spent making the plans were recorded. The permutation test and a random effects model were used to analyze the data. **Results:** The treatment plans arrived at with digital and plaster models were similar. With respect to extractions, the mean difference between digital and plaster formats was 11.9% (95% CI, 7.5%-16.3%). For surgery, the mean difference was 9.4% (95% CI, 5.0%-13.8%). There was no significant difference in the agreement rate between those who viewed models in different formats compared with those who viewed models twice in the same format ($P > 0.05$). The time spent to plan treatment with plaster models was not significantly different from the time spent with digital models ($P = 0.87$). **Conclusions:** Based on this study, digital models can be substituted for plaster models with no significant differences in the final plans, the reliability of the plans, and the time required to create the plan. (Am J Orthod Dentofacial Orthop 2019;155:135-42)

With the advent of modern intraoral scanners, digital models are gradually replacing plaster study models in orthodontics.[1-3] There are many advantages to digital models, including easier storage, sharing, and manipulation. However, orthodontists find familiarity in plaster models that can be physically articulated and measured, and studies have reported that models are the single most important orthodontic record for treatment planning.[4,5] Therefore, studies assessing the accuracy of digital models and their impact on treatment planning are necessary.

Digital models first became available in orthodontics in 1999 and were created by scanning plaster models poured from impressions.[6] Authors of several studies have looked at the accuracy of this method of digital model creation; in general, digital models have been found to be reasonably accurate compared with plaster models.[7-11] In the past decade, intraoral scanners have become more readily available for orthodontic practices, and a recent systematic review assessed studies specifically using intraoral scanners. The 4 studies in the review showed that digital models created with intraoral scanning are as accurate and reliable as plaster models from conventional impressions.[12-16]

An important question now might be whether assessing digital vs plaster models influences the treatment plan formed by the orthodontist for a particular patient. Two studies have reported on using digital models vs plaster models, with no large differences in treatment decisions.[17,18] In 1 study, only Class II subjects were assessed.[17] In the other, all patients were first planned

for treatment using digital models, and immediately af-
ter reaching a final treatment plan with the digital casts,
the orthodontists were given the plaster casts and asked
to plan them again.[18] Thus, 1 study is not generalizable
to all malocclusions, and the other may suffer from the
lack of a washout time between the 2 assessments. A sys-
tematic review reported on these 2 studies and
concluded that digital models could be adequate to
replace plaster models in Class II malocclusion treatment
planning but did not provide sufficient evidence for all
other malocclusion types and discrepancies.[19] With
these limitations, as well as the great improvements to
orthodontic imaging hardware and software over the
past decade, it seemed timely to conduct additional
studies about treatment planning with digital models.
Therefore, the purpose of this study was to investigate
differences in orthodontists' treatment plans when as-
sessing digital models, compared with plaster models.
We investigated treatment plans for a variety of maloc-
clusion types and discrepancies. Additionally, the impact
of digital vs plaster models on the reliability of ortho-
dontists' treatment plans and the time required to plan
the patients was investigated. The null hypothesis was
that orthodontists arrive at the same treatment plans
with plaster and digital models, and that different for-
mats of models do not influence the reliability of the
plan or the time required to formulate the plan.

MATERIAL AND METHODS

This project was approved by the Human Subjects Di-
vision at the University of Washington. Sixteen ortho-
dontists, divided into 2 groups of 8, were recruited. All
had been in practice for a minimum of 5 years and did
not routinely use digital models in their practices (other
than for Invisalign patients). The groups were made as
comparable as possible by considering sex and time in
practice for the assignment. The demographics of the
2 groups are shown in Table I. The orthodontists were
familiarized with the OrthoCad software (Align Technol-
ogy, San Jose, Calif) just before viewing the patient re-
cords in the study.

Twenty initial patient records were identified from
the patient population at the University of Washington's
orthodontic clinic. These patients had all been treated
and were divided into 2 sets of 10 with similar distribu-
tions of malocclusions, including various degrees of
crowding, transverse, anteroposterior, and vertical prob-
lems. A summary of these subjects is presented in
Table II.

Since all patients before 2015 at the University of
Washington orthodontic clinic had physical models,
the iTero HD 2.9 intraoral scanner (Align Technology)

Table I. Demographic characteristics of the orthodontists

Group of orthodontists	1 Assessed models with same format Digital-digital or plaster-plaster	2 Assessed models with different format Digital-plaster or plaster-digital
Sex		
Male	6	4
Female	2	4
Years in practice		
Average	22.8	27.6
<10	2	1
11-20	1	1
21-30	2	3
>30	3	3

was used to create digital models by scanning the phys-
ical models in the iRecord mode. The digital casts were
imported to the OrthoCad software (Align Technology),
and this program was used for viewing the digital
models. The digital panoramic radiographs, cephalo-
grams, and photos for each patient were also collected,
and these records, along with the digital or plaster casts,
formed the diagnostic records. All patient identifiers
were removed, and the orthodontists only saw a study
number when they viewed the records. A standardized
form for each patient was used, so that the orthodontists
could record information about each subject in a sys-
tematic manner (Fig 1).

The orthodontists assessed a total of 20 patients at
the beginning of the study (T1) and reassessed them
again at least 3 months later (T2). Therefore, the evalu-
ators could not easily recall their previous decisions.
Study casts, panoramic radiographs, cephalograms,
and photos were presented at each time. Depending
on a predetermined assignment scheme, these subjects
assessed at the 2 times could have had the same format
of models or a different format (Fig 2). The assignment
scheme ensured that all combinations of assessment
with digital and plaster models were equally distributed
over the 2 times. This information was used to determine
whether the type of model affected the orthodontist's
treatment plan for a particular patient.

The treatment plan decisions were recorded and
used to investigate the treatment plans between digital
and plaster models. First, the percentages of extraction
and surgical recommendations were calculated for each
subject, based on the format of the models, and these
values were used to obtain the percentage difference
for each subject (eg, in case 1-1, if the extraction per-
centages were 75% with plaster models and 50% with

Table II. Summary of patient characteristics

		Set 1			Set 2			
	Pair	*Case number*	*Age*	*Sex*	*Case number*	*Age*	*Sex*	*Main condition of interest*
Class I	1	1-1	15 y 1 mo	F	1-2	16 y 6 mo	F	Crowding
	2	2-1	14 y 5 mo	M	2-2	14 y 9 mo	M	Crowding
	3	3-1	21 y 9 mo	M	3-2	22 y 11 mo	M	Adult; posterior crossbite
	4	4-1	13 y 7 mo	M	4-2	14 y 2 mo	M	Anterior open bite
Class II Division 1	5	5-1	13 y 4 mo	F	5-2	13 y 5 mo	F	Crowding
	6	6-1	13 y 9 mo	F	6-2	12 y 8 mo	F	Deepbite
Class II Division 2	7	7-1	14 y 1 mo	F	7-2	12 y 7 mo	F	Adolescent; deepbite
	8	8-1	30 y 9 mo	F	8-2	28 y 9 mo	F	Adult
Class III	9	9-1	15 y 5 mo	F	9-2	15 y 1 mo	F	Mild anteroposterior discrepancy
	10	10-1	16 y 6 mo	F	10-2	16 y 7 mo	F	Severe anteroposterior discrepancy

F, Female; *M*, male.

```
Case 7-1        No.1000063      Female    14y1m

Chief Complaint:    I really hate that I have vampire fangs

First Menses:    2 years ago
═══════════════════════════════════════════════════════════
1. Please circle the treatment plan you would recommend to this patient (OK to circle more than one).

    a. Headgear

    b. Functional appliances

    c. Temporary anchorage devices

    d. Orthognathic Surgery            If Yes, circle arch(es)      Maxilla        Mandible

    e. Maxillary expansion

    f. Other treatments or techniques (specify)_____

    g. None of the above
─────────────────────────────────────────────────────────────
2. Please circle if extractions or interproximal reduction are a part of your recommended plan?

    a. Extraction:    If Yes, indicate teeth:




    b.: IPR:        If Yes, circle arch(es)      Maxilla       Mandible
─────────────────────────────────────────────────────────────
    3. Is the patient a good candidate for Invisalign® treatment?        Yes        No

If no, please specify why _____
```

Fig 1. Sample data collection form.

digital models, the difference would be 25%). Using absolute values for these differences, the mean difference for all 20 subjects was calculated, along with a 95% confidence interval. Additionally, the reliability of treatment decisions when orthodontists planned with the same format at T1 and T2 was assessed, compared with different formats at T1 and T2. Finally, the time that each orthodontist spent planning with digital vs plaster casts was recorded, and these times were compared at T1 and T2.

Statistical analysis

The permutation test was used to assess whether there was a difference between the treatment decisions related to surgery and extraction between the digital model group and the plaster model group at T1. The mean differences in extraction and surgery rates for plaster and digital casts were calculated, and 95% confidence intervals were constructed. The permutation test was used to assess whether there was a difference
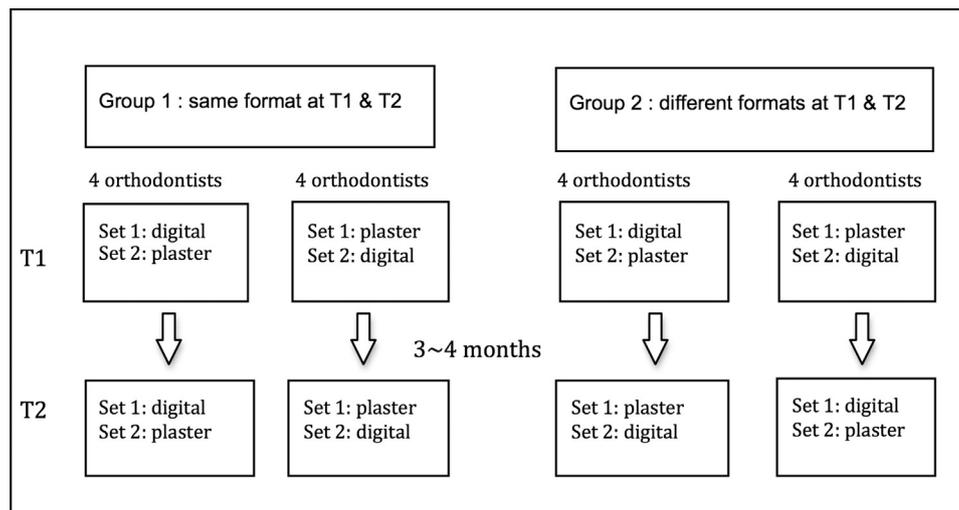
Fig 2. Scheme for treatment-planning assignment of orthodontists and patients.

between the agreement levels of those who viewed models twice with different formats compared with those who viewed models twice with the same format. The level of significance was set at P <0.05. A random-effects model was used to compare the time spent on treatment planning with digital and plaster models at T1 and T2.

RESULTS

The subjects' characteristics and the most commonly recommended treatment plans are shown in Table III. The most common treatment plan for digital or plaster models was the same for all patients, with the exception of cases 3-2, 6-1, and 7-2. In 3-2 and 6-1, the orthodontists in both the digital and plaster groups recommended premolar extractions and orthognathic surgery most frequently, but with a reversal in their percentages. In 7-2, orthognathic surgery (50%) was most commonly chosen with the digital model, whereas functional appliances (62.5%) were most commonly chosen with plaster models. With respect to extractions, there was an 11.9% mean difference between decisions made with digital and plaster formats at T1. For surgery, the mean difference was 9.4% between digital and plaster formats at T1 (Table IV). These differences were statistically significant.

The intrarater agreement for each treatment option is shown in Table V. To prevent artificially inflating the agreement, patients for whom no orthodontist recommended a particular option at T1 were removed, because that option was essentially not realistic for that patient. For example, patients who had no recommendations for extractions were removed from the analysis of

agreement for the extraction option. There was no significant difference in the agreement rate between those who viewed models twice with different formats compared with those who viewed models twice with the same format (P >0.05).

The intrarater agreement rates for surgery or no surgery were 78% for the different formats group and 80% for the same format group. There was no significant difference between these rates (P = 0.55). The agreement rates for surgery pattern with the different format group were reduced to 74% but remained at 80% for the same format group (P = 0.17).

The intrarater agreement for extraction or no extraction was 83% for both groups (P = 0.72). The agreement rates for extraction pattern were reduced to 71% for the different formats group and 70% for the same format group (P = 0.82). There was no significant difference between them.

The agreement rates for functional appliance decisions were 75% for the different formats group and 78% for the same format group (P = 0.25). The agreement rates for headgear decisions were 82% for the different formats group and 88% for the same format group (P = 0.10). The agreement rates for temporary anchorage devices were 91% for the different formats group and 84% for the same format group (P = 0.22). The agreement rates for maxillary expansion decisions were 81% for the different formats group and 84% for the same format group (P = 0.13). The agreement rates for interproximal reduction decisions were 77% for the different formats group and 78% for the same format group (P = 0.12). There

Table III. Patient characteristics and the most commonly recommended treatment plans at T1

		Set 1					Set 2		
Pair	Case number	Main characteristics	Most commonly recommended treatment plans at T1 (digital)	Most commonly recommended treatment plans at T1 (plaster)	Case number	Main characteristics	Most commonly recommended treatment plans at T1 (digital)	Most commonly recommended treatment plans at T1 (plaster)
1	1-1	Moderate crowding, protrusive profile	Premolar extractions (100%)	Premolar extractions (87.5%)	1-2	Moderate crowding, maxillary right lateral crossbite, straight profile	Nonextraction with IPR (62.5%); maxillary expansion (37.5%)	Nonextraction with IPR (62.5%); maxillary expansion (37.5%)
2	2-1	Moderate to severe crowding; high canine	Premolar extractions (75%)	Premolar extractions (75%)	2-2	Moderate to severe crowding; maxillary lateral incisors in crossbite	Premolar extractions (87.5%)	Premolar extractions (87.5%)
3	3-1	Adult, severe crowding, bilateral posterior crossbite	Premolar extractions (87.5%)	Premolar extractions (62.5%); maxillary arch expnsion (25%)	3-2*	Adult, unilateral posterior crossbite, severely proclined maxillary incisors, Class II	Premolar extractions (62.5%); orthognathic surgery (37.5%)	Orthognathic surgery (62.5%); premolar extractions (37.5%)
4	4-1	Anterior open bite; facial asymmetry	Orthognathic surgery (50%); premolar extractions (37.5%)	Orthognathic surgery (37.5%); premolar extractions (25%); maxillary expansion (25%)	4-2	Anterior open bite; mild crowding; protrusive lips	Premolar extractions (87.5%)	Premolar extractions (100%)
5	5-1	Moderate crowding	Premolar extractions (75%)	Premolar extractions (87.5%)	5-2	Moderate crowding	Premolar extractions (87.5%)	Premolar extractions (87.5%)
6	6-1	Deepbite; full-cusp Class II, retrognathic mandible	Orthognathic surgery (62.5%); premolar extractions (37.5%)	Premolar extractions (62.5%); orthognathic surgery (37.5%)	6-2	Deepbite; half-cusp Class II	Functional appliances (50%); premolar extractions (25%)	Functional appliances (62.5%)
7	7-1	Deepbite; maxillary moderate crowding	Premolar extractions (25%); functional appliances (25%)	Premolar extractions (25%); functional appliances (12.5%)	7-2	Deepbite	Orthognathic surgery (50%)	Functional appliances (62.5%); orthognathic surgery (25%)
8	8-1	Adult; deepbite	Orthognathic surgery (50%); IPR (25%)	Orthognathic surgery (50%); premolar extractions (25%)	8-2	Adult; severe crowding	premolar extractions (75%); orthognathic surgery (25%)	premolar extractions (87.5%)
9	9-1	Mild anteroposterior discrepancy, asymmetry	Orthognathic surgery (62.5%)	Orthognathic surgery (87.5%)	9-2	Mild anteroposterior discrepancy, asymmetry	Nonextraction (75%); orthognathic surgery (25%)	Nonextraction (100%)
10	10-1	Anterior crossbite, severe anteroposterior discrepancy, asymmetry	Orthognathic surgery (62.5%)	Orthognathic surgery (62.5%)	10-2	Anterior crossbite, severe anteroposterior discrepancy, asymmetry	Orthognathic surgery (75%)	Orthognathic surgery (87.5%)

IPR, Interproximal reduction.
*Patient had Class II molar relationship.

Table IV. Percentages of surgery and extraction at T1

	Absolute difference	95% CI	
Surgery	9.40%	5.00%	13.80%
Extraction	11.90%	7.50%	16.30%

was no significant difference for any of these options. Thus, the orthodontists' agreement rates between their first and second plans did not appear to be influenced by the type of dental models they used.

The mean times spent on treatment planning were 104 seconds with digital models at T1 and 99 seconds with plaster models; these were not significantly different ($P = 0.20$). Likewise, at T2, the mean treatment planning times were 90 seconds with digital models and 96 seconds with plaster models ($P = 0.14$). The time spent to arrive at the treatment plan with a plaster model was not significantly different from the time spent with a digital model ($P = 0.87$) (Table VI). However, there was a statistically significant difference between time spent by the orthodontists at the 2 times, with less time at T2 ($P = 0.005$), regardless of the format.

DISCUSSION

The purpose of this study was to investigate whether viewing digital or plaster study casts would affect the treatment-planning decisions of the orthodontists for a particular patient. Treatment planning requires the orthodontist's ability to analyze multiple diagnostic records, including dental models, which are essential for presenting the patient's occlusion and other dental characteristics. Overall, the orthodontists in this study, who did not routinely use digital models, had relatively good agreement in their most recommended treatment plans, regardless of whether digital or plaster models were used. Additionally, there was similar intraorthodontist agreement between the treatment plans at T1 and T2, regardless of the order of presentation, or whether they viewed the same or a different format. Finally, the amount of time spent viewing digital vs plaster models was similar during the treatment-planning sessions. This indicates that digital models are adequate for treatment planning and can substitute for plaster models, even for orthodontists who have little experience viewing digital models.

In the study by Rheude et al,[18] 12% of mechanical procedures and 6% of treatment plans from the first time point with digital models changed after the orthodontist viewed the plaster model, indicating good agreement with the plans from the digital and plaster models.

In our study, about 20% of the orthodontists changed their final treatment plan at T2. This difference is considerably higher than that reported by Rheude et al, but they had no washout time between the 2 treatment plans, and this could have resulted in the high agreement. To prevent overestimation in our study, at least 3 months passed between the 2 assessment times. Furthermore, Rheude et al assessed the digital models first, followed by the plaster models. The sequence of model analysis could have produced a systematic bias. In our study, a predetermined scheme was used to eliminate any systematic bias, since each combination of plaster and digital models at T1 and T2 was equally used (Fig 2). Although the number of orthodontists in this study was not large, each orthodontist served as his or her own control.

In the study by Whetten et al,[17] good agreement was noted for surgery, extractions, and auxiliary appliances. Overall agreement rates ranged from 78% to 87%. There was no statistical difference in intrarater treatment-planning agreement, but those authors assessed only Class II malocclusions. We assessed a variety of malocclusions (including anteroposterior discrepancy, crowding, and vertical problems), and the agreement for surgery and extraction decisions made at T1 with plaster vs digital models was similar to that reported by Whetten et al.

It has been reported that the frequency of variation in diagnosis between digital and plaster models decreases as orthodontists gain experience with digital models.[19] Interactive 3-dimensional digital model software enables orthodontists to manipulate the dental models virtually, similar to plaster models. In this study, the time spent to arrive at the treatment plan with plaster models was not different from the time needed with digital models. Thus, the format of the models did not affect the efficiency of making the treatment plans, even though the orthodontists had limited experience with the viewing software. It has been argued that the high definition of 3-dimensional imaging software benefits the orthodontist's decision process, but this has not yet been proven.[20]

As in all studies, there were both strengths and limitations. In this study, we included subjects with various degrees of crowding, transverse, anteroposterior, and vertical problems. Thus, our results were treatment plans covering wide distributions of malocclusions. To prevent bias, a predetermined assignment scheme was created to ensure that all combinations of digital and plaster models were equally distributed over the 2 times. Also, the patients and the practitioners were matched as much as possible. One limitation was that the number of orthodontists recruited in this study was not large.

Table V. Intrarater agreement when viewing patient twice

	Model		Difference in agreement	95% CI of difference		P value
	Different formats	Same format				
Orthognathic surgery? (yes/no)*	78%	80%	−3%	−14%	9%	0.55
If surgery yes, which jaw(s)?	74%	80%	−6%	−15%	4%	0.17
Extractions? (yes/no)*	83%	83%	−1%	−9%	8%	0.72
If extractions yes, which teeth?	71%	70%	1%	−10%	12%	0.82
Functional appliance*	75%	78%	−3%	69%	−38%	0.25
Headgear*	82%	88%	−6%	40%	−22%	0.1
Temporary anchorage device*	91%	84%	6%	34%	−10%	0.22
Expansion*	81%	84%	−2%	70%	−19%	0.13
IPR*	77%	78%	−1%	93%	−14%	0.12

IPR, Interproximal reduction.
*Removed subjects when all practitioners agreed on course of action at initial treatment plan.

Table VI. Time to perform treatment plan

		Effect	95% CI		P value
Model	Digital	1	-	-	0.87
Type	Plaster	101%*	95%	107%	
Time	T1 model	1	-	-	0.005
Point	T2 model	92%*	86%	97%	

*Random effects model: practitioner and case entered as random effects.

However, each orthodontist served as his or her own control when assessing the reliability of the treatment plans. Also, 1 of the 10 patient pairs was not perfectly matched (pair 3). Both subjects were matched for sex and age, and both had posterior crossbites, which was the condition of interest. However, 1 subject had a Class I molar relationship, and the other had a Class II molar relationship. Finally, the digital models used in this study were scanned from plaster models, not directly from a patient's mouth. Although there could be some inaccuracies in the plaster models that were then transferred to the digital models, this technique ensured that the plaster and digital models were as similar as possible. Thus, the dentition and dental relationships should have been identical in both formats.

CONCLUSIONS

1. The treatment plans arrived at using digital vs plaster models were similar with a variety of malocclusions.
2. The intrarater agreement rates when planning treatment with digital and plaster casts at 2 times were similar with various malocclusions.
3. The time spent viewing digital vs plaster models for treatment planning was similar with a variety of malocclusions.

REFERENCES

1. Stevens DR, Flores-Mir C, Nebbe B, Raboud DW, Heo G, Major PW. Validity, reliability, and reproducibility of plaster vs digital study models: comparison of peer assessment rating and Bolton analysis and their constituent measurements. Am J Orthod Dentofacial Orthop 2006;129:794-803.
2. Gracco A, Buranello M, Cozzani M, Siciliani G. Digital and plaster models: a comparison of measurements and times. Prog Orthod 2007;8:252-9.
3. Mangiacapra R, Butti AC, Salvato A, Biagi R. Traditional plaster casts and dental digital models: intra-examiner reliability of measurements. Prog Orthod 2009;10:48-53.
4. Han UK, Vig KW, Weintraub JA, Vig PS, Kowalski CJ. Consistency of orthodontic treatment decisions relative to diagnostic records. Am J Orthod Dentofacial Orthop 1991;100:212-9.
5. Nijkamp PG, Habets LL, Aartman IH, Zentner A. The influence of cephalometrics on orthodontic treatment planning. Eur J Orthod 2008;30:630-5.
6. Peluso MJ, Josell SD, Levine SW, Lorei BJ. Digital models: an introduction. Semin Orthod 2004;10:226-38.
7. Hayashi K, Sachdeva AU, Saitoh S, Lee SP, Kubota T, Mizoguchi I. Assessment of the accuracy and reliability of new 3-dimensional scanning devices. Am J Orthod Dentofacial Orthop 2013;144:619-25.
8. Sousa MV, Vasconcelos EC, Janson G, Garib D, Pinzan A. Accuracy and reproducibility of 3-dimensional digital model measurements. Am J Orthod Dentofacial Orthop 2012;142:269-73.
9. Costalos PA, Sarraf K, Cangialosi TJ, Efstratiadis S. Evaluation of the accuracy of digital model analysis for the American Board of Orthodontics objective grading system for dental casts. Am J Orthod Dentofacial Orthop 2005;128:624-9.
10. Leifert MF, Leifert MM, Efstratiadis SS, Cangialosi TJ. Comparison of space analysis evaluations with digital models and plaster dental casts. Am J Orthod Dentofacial Orthop 2009;136:16.e1-4: discussion 16.
11. Santoro M, Galkin S, Teredesai M, Nicolay OF, Cangialosi TJ. Comparison of measurements made on digital and plaster models. Am J Orthod Dentofacial Orthop 2003;124:101-5.

12. Aragon ML, Pontes LF, Bichara LM, Flores-Mir C, Normando D. Validity and reliability of intraoral scanners compared to conventional gypsum models measurements: a systematic review. Eur J Orthod 2016;38:429-34.
13. Grunheid T, McCarthy SD, Larson BE. Clinical use of a direct chairside oral scanner: an assessment of accuracy, time, and patient acceptance. Am J Orthod Dentofacial Orthop 2014;146:673-82.
14. Flugge TV, Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofacial Orthop 2013;144:471-8.
15. Wiranto MG, Engelbrecht WP, Tutein Nolthenius HE, van der Meer WJ, Ren Y. Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. Am J Orthod Dentofacial Orthop 2013;143: 140-7.
16. Naidu D, Freer TJ. Validity, reliability, and reproducibility of the iOC intraoral scanner: a comparison of tooth widths and Bolton ratios. Am J Orthod Dentofacial Orthop 2013;144:304-10.
17. Whetten JL, Williamson PC, Heo G, Varnhagen C, Major PW. Variations in orthodontic treatment planning decisions of Class II patients between virtual 3-dimensional models and traditional plaster study models. Am J Orthod Dentofacial Orthop 2006; 130:485-91.
18. Rheude B, Sadowsky PL, Ferriera A, Jacobson A. An evaluation of the use of digital study models in orthodontic diagnosis and treatment planning. Angle Orthod 2005;75:300-4.
19. Pacheco-Pereira C, De Luca Canto G, Major PW, Flores-Mir C. Variation of orthodontic treatment decision-making based on dental model type: a systematic review. Angle Orthod 2015;85:501-9.
20. Yagi M, Ohno H, Takada K. Computational formulation of orthodontic tooth-extraction decisions. Part II: which tooth should be extracted? Angle Orthod 2009;79:892-8.